University of California, Los Angeles
MAE 259B - Control of Robotic Systems

Elastic Tube Motion in 3D Vascular-mimicking Network

Team 8

Mingzhang Zhu
Zhengqi Zhong
YaoHsing Tseng

Introduction

Soft continuum robots with active steerable probes capable of navigating in a complex vascular network hold great promise for medical applications, especially useful in the elimination of thrombosis or lesions located at hard-to-reach anatomies [1]. However, the mechanical properties of the robots such as steering angle and bending radius may limit the reachable anatomies [2]. Therefore, simulation of a robot navigating to the desired location within a constrained and complex environment is critical for the surgeons to determine the most suitable treatment for patients. In this project, we aimed to demonstrate a simulation of an elastic tube with a steerable probe navigating through a complex environment to the desired location with the use of discrete elastic rods analysis.

Background

Robots have been applied to surgery for several years. However, the design of these robots makes it difficult to scale the size down to implement several types of surgeries, such as brain and heart surgeries. In recent years, several solutions have been found, and the most significant one is the soft continuum robots which aim to achieve minimally invasive surgery (MIS). With this specific design, surgical robots can be reduced to submillimeter-scale, and work in more complex and constrained environments. For example, robots can navigate to the target point surrounded by cardiac and important soft tissues. In this work, we aim to reconstruct a soft continuum robot and simulate it, finishing several tasks to mimic how this robot actually works in real-life tasks.

Objective

The objective of this project is to simulate an elastic tube with a steerable probe navigating to the desired location within a complex vascular network. The potential application includes eliminating the thrombosis or lesions caused by arterial aneurysms or strokes in arteries or anatomies.

This robot is designed to have three degrees of freedom: axial translation, axial rotation, and distal tip bending. The maximum bending angle of the steerable tip is designed to be about 120 degrees, while the minimum bending radius equals three times the radius of the elastic tube, which enables the robot to navigate to hard-to-reach cerebrovascular anatomies.

The first milestone of this project is that the continuum robot would navigate to the desired location in a 2D plane to verify the feasibility of our simulation method. After that, the navigation process will be simulated in a three-dimensional vascular network environment to mimic the real scenario. The completeness of the three-dimensional simulation will depend on the progress due to the time limit.

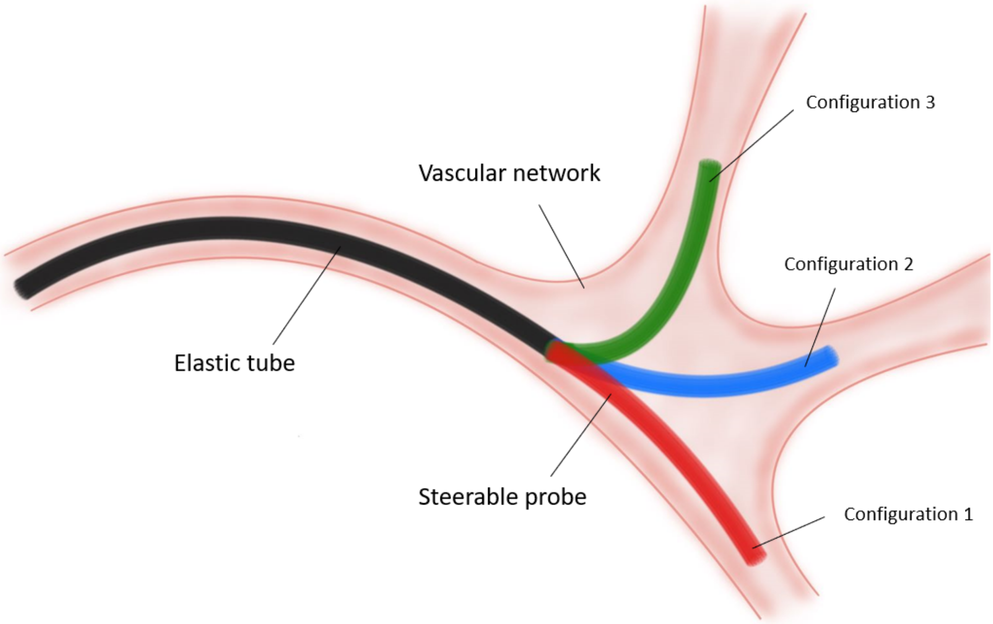

Figure 1: Illustration of an active steerable probe of a soft continuum robot navigating a complex vascular network. Three configurations are listed to demonstrate different bending angles of the distal tip.

Methods

To implement this simulation, first, we need to characterize the body of the soft continuum robot (elastic tube) using discrete tube formulation and Newton-Raphson iteration. The steerable distal tip will be simulated by applying a force vector with several constraints. External forces such as friction between the elastic rod and the inlining of the vessels would also be considered to mimic the real scenario. After that, both internal and external force vectors will be integrated with the elastic tube model. Additionally, a virtual environment containing a 2D or 3D vascular network is required to be constructed to demonstrate the simulation results. Challenges including collision detection and reaction are expected.

Discussion

We have two distinguished potential simulation methods, and they have very different technologies. We need to choose one of them as our future direction.

1. The tip of the soft robot is magnetism, so an external magnetic field can control it to move inside a human's body. This method allows humans to control the head of the soft robot directly by modifying the magnetic field around the human body. The rest of the robot body can be assumed to follow the head's trajectory. This method does not require much computational power. However, since a large magnetic field generator is required, the energy consumption is substantial.

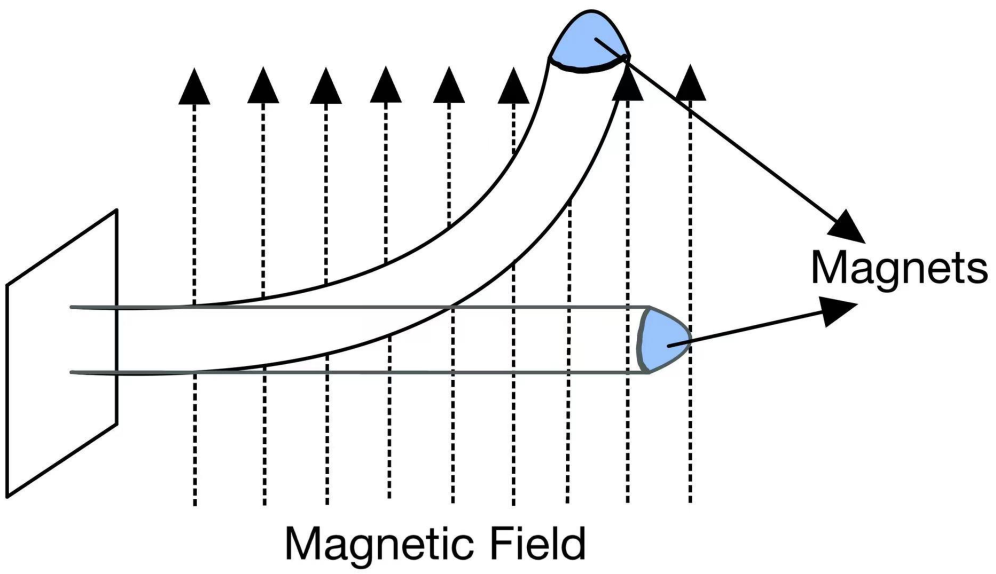

Figure 2: Robot Curving under influence of Magnetic Filed

2. The head of the soft robot is designed to have 1 degree of freedom and bend in a certain direction. Therefore, when facing a curving or junction pathway, the robot's head can bend to the desired direction as guidance for the rest of the body. As a result, the back and forth robot movement is controlled by pushing and pulling the robot's end at a specific position and orientation. The robot's turning is controlled by curving the head and pushing the end. This method requires a little energy consumption, but the simulation and control method requires enormous computation power.

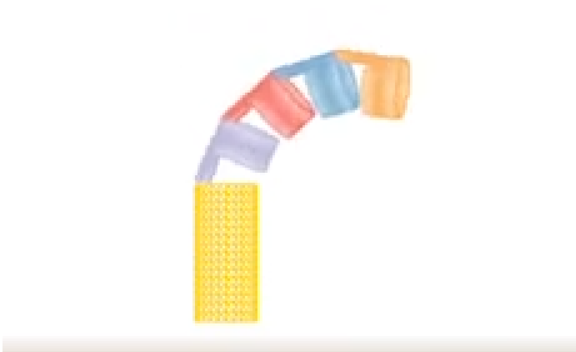
Figure 3: Steerable Probe Robot Head Demonstration

Project Timeline

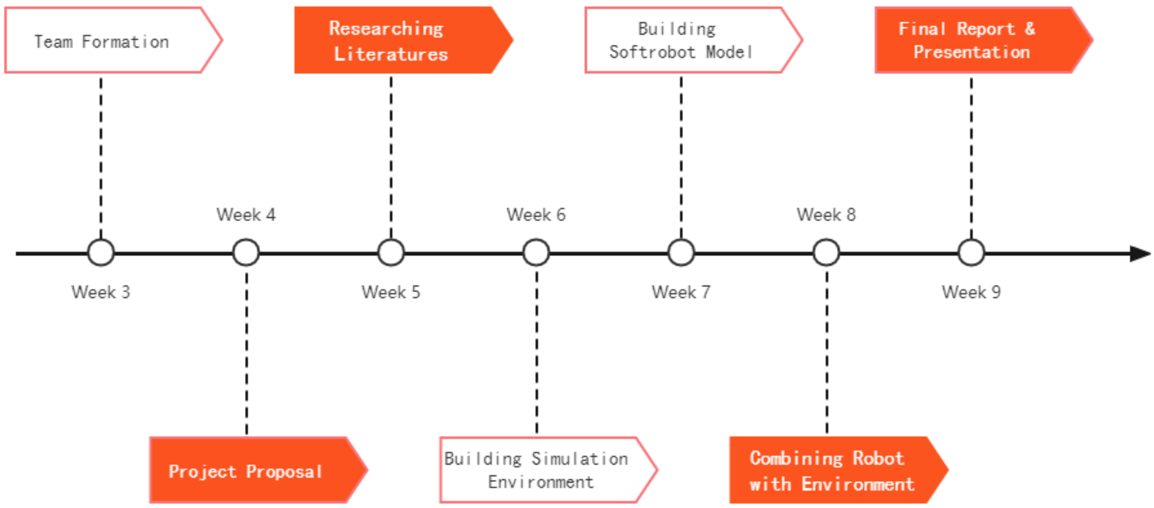

Figure 4: Team 8 Project Timeline

Reference

1. Cianchetti, M., Laschi, C., Menciassi, A. et al. Biomedical applications of soft robotics. Nat Rev Mater 3, 143–153 (2018).
2. H. Rafii-Tari, C. J. Payne, G.-Z. Yang, Current and emerging robot-assisted endovascular catheterization technologies: A review. Ann. Biomed. Eng. 42, 697–715 (2014).